



The analysis of suppositions included in the Polish Energetic Policy using the LCA technique—Poland case study



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ABSTRACT

The paper presents the use of Life Assessment Analysis (LCA) to determine the environmental impact of produced electricity and heat for power plants and coal-fired plants in Poland. Moreover, the usefulness of this method of assessment for energy sector was demonstrated. The article also presents the comparative analysis of energy production from burning solid fuels with the use of Ecoindicator 99. The conducted LCA analyses aimed at undergoing a critical review of the objectives of Polish energetic policy. The difference was presented concerning the results of the environmental impact as well as the causes of the essential values of the impact were discussed. Furthermore, the authors identified the measures which will contribute to the reduction of the impact of electricity production on the environment during the production of electricity in the future.

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1. Introduction

The energy sector in Poland is currently undergoing significant transformations [1]. Aging energy infrastructure in combination with increasing demand for energy as well as higher ecological standards are forcing energy companies to undertake investment activities. *Polish energetic policy until 2030* is a document which indicates the results, that the measures mentioned earlier, should generate, they are as follows:

- Improving energy efficiency;
- increased security of fuel and energy; and
- other [2]. pp. 4–5, [3]

Polish energetic policy also refers to improving energy efficiency, where the following main objectives are articulated, aiming at [2], p. 6:

- Achieving zero-energy economic growth, i.e. economic development without the increase of demand for primary energy, and
- reducing the energy intensity of economy in Poland by 2030 to the level of EU-15 from 2005.

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The main objective of energy policy in the field is to ensure ongoing meeting of demand for energy, taking into account the maximum possible use of domestic resources and environmentally friendly technologies.

Specific objectives in the field are as follows:

- Building new generation capacity to balance domestic demand for electricity and maintain the operationally available power surplus during the peak generation capacity of domestic conventional and nuclear generation sources at the minimal level of 15% of the maximum domestic demand for electricity;
- Building intervention sources of electricity generation essential to security of the power system operation;
- Developing the national transmission system enabling sustainable economic development of Poland, its individual regions and ensuring reliable electricity supplies to agglomerations (particularly closing the 400 kV loop and loops circling Poland's largest cities), as well as receipt of electricity from the areas with a large number of planned and newly built generation facilities, including in particular the wind farms.
- Developing cross-border connections coordinated with extending the domestic transmission system as well as the systems in neighboring countries, which will allow to exchange at least 15% of electricity used in Poland by 2015, 20% by 2020, and 25% by 2030;
- Modernization and extension of the distribution grid which allows to improve the reliability of power supply and to develop distributed power generation using local sources of energy;
- Modernization of transmission and distribution grids to reduce failure frequency by 50% by 2030 as compared to 2005;
- Aiming at replacing the heat and power plans supplying the centralized heat distribution systems of Polish cities with cogeneration sources by 2030.

The point of reference to the necessity of dispersing the sources of energy production and co-existence of cogeneration is of particular importance. The aim of the paper is to confirm the correctness of ecological objectives included in the document *Polish energetic policy until 2030*.

Poland, as a country obtaining electricity primarily in coal-fired power plants cannot, however, suddenly leave the present structure of electricity generation. It will be a process of an evolutionary nature, spread over decades [4]. Therefore, the way of generating electricity in Polish power plants, in particular coal-fired ones, should be monitored professionally. It will allow assessing properly the use of non-renewable resources, comparing the economic and ecological efficiency of the existing technologies of energy production as well as reducing the amount of harmful emissions into the atmosphere in accordance with the objectives of *Polish energetic policy*.

One of the effective methods, which helps to evaluate and compare the environmental impact of the electricity production in different power plants based on the same fuels is Life Cycle Assessment (LCA) [5,6]. The analysis with LCA can include both products, processes with the full life cycle of the product, and the whole industries. The paper presents the analysis with the LCA method, which will allow for the evaluation and comparison of electricity production in two heat and power plants (cogeneration) mainly coal-fired: CHP Lubin, CHP Polkowice and two power plants—Dolna Odra and Opole, where cogeneration is a secondary element.

Adding life cycle assessment to the decision-making process provides the understanding of the human health and environmental impacts not traditionally considered when selecting a produce or process. This valuable information provides a way to

account for the full impacts of decisions, especially those that occur outside the site, that are directly influenced by the selection of a product or process.

Performing a complete LCA requires significant resources. Usually, at least part of the data needed is taken from generic data or another analysis. The LCA practitioner must keep the scope and aim of the study clearly in mind and avoid taking shortcuts where these might compromise the objective.

Energy production has obvious health and environmental impacts. There are significant variations between different energy production forms in this respect. Therefore it is important to apply the LCA methodology for comparison of health and environmental impacts of various energy forms.

The introduction (part 1) presents aims and objectives of the Polish Energy Policy, going from the general to details. Part 2 contains a description of the research methodology in combination with definition of the functional unit and system boundaries. Section 3 presents the results of the LCA power plants combined with information on technical data of boilers. This section provides the results of the LCA discussion. In Section 4 the results are discussed in the context of the requirements to reduce emissions and the need to improve energy efficiency, e.g. through the use of local cogeneration. The main conclusions of the paper are summarized in Section 5.

2. Material and methods

Life Cycle Assessment is an established method, which aims at determining environmental risks. The LCA analysis is based on the identification and determination of the amount of used resources, energy and waste as well as discharged pollution, and then on the evaluation of the impact of these elements on the environment. This method allows for the identification of threats and assigning the ways of improving the quality of the environment. One of the most important tasks of the LCA method is to study the possible impacts of the manufacturing process on the environment.

A significant feature of the LCA analysis is the possibility of studying the influence on the environment throughout the whole “life” cycle of the product. With LCA it is possible to determine the impact of a particular product on the environment not only when generating and obtaining raw materials, but also during its use until disposal. LCA allows supporting the optimal management of the limited resources, as it is based on the actual material-energetic flows of the examined process. The methodology of LCA analysis is defined in two standards: ISO 14040:2006 and ISO 14044:2006. Due to its versatility of use, the methodology of the analysis has been described in numerous scientific publications.

ISO norms clarify requirements in relation to conducting LCA. The Life Cycle Assessment concerns environmental aspects and possible impacts on the environment in the period of product life starting from gathering resources, through production, use, processing after being removed from exploitation, recycling, up to the final disposal (i.e. “from the cradle to the grave”). There are four stages of LCA analysis distinguished as follows:

- Stage of defining the aim and scope,
- stage of analyzing the in and out set,
- stage of assessing the impact and
- stage of interpretation.

The scope, together with borders of the system and the level of accuracy of LCA, depends on the object and intended use of the studies. The profoundness and extent of LCA studies can differ substantially depending on the aim of a particular LCA analysis.

Table 1

Categories of damages and impacts in Eco-Indicator 99 method.

Source: own study based on computer software SimaPro.

Damage category	Impact category
Human health	Carcinogens
	Respiratory organics
	Respiratory inorganics
	Climate change
	Radiation
Ecosystem quality	Ozone layer
	Ecotoxicity
	Acidification/
	Eutrophication
Resources	Land use
	Minerals
	Fossil fuels

The results and conclusions of the LCA shall be completely and accurately reported without bias to the intended audience. The results, data, methods, assumptions and limitations shall be transparent and presented in sufficient detail to allow the reader to comprehend the complexities and trade-offs inherent in the LCA.

The critical review process ensures the following [7,8]:

- The methods used to carry out the LCA are consistent with ISO 14044,
- the methods used to carry out the LCA are scientifically and technically valid,
- the data used are appropriate and reasonable in relation to the goal of the study,
- the interpretations reflect the limitations identified and the goal of the study, and
- the study report is transparent and consistent.

The LCA analysis is supported by various commercial computer programmes available on the market. The analysis used computer program SimaPro developed by PRe Consultants B.V. in the Netherlands. Computer program SimaPro in version 7.1, among a dozen methods of impact assessment, offers the Eco-Indicator 99 method. This method allows for estimating the environmental impact of each stage of the energy production process, especially when it comes to the impact category of “fossil fuels”. This aspect is important for the study of the environmental impact of electricity production in Polish coal-fired power plants. LCA analysis enables the presentation of the results of the environmental impact in relation to eleven impact categories, which can be grouped into three damage categories [9–19]. Relations between categories of damages and impacts are presented in Table 1.

The most important tasks of LCA are the following [20]:

- Documentation of possible impacts of a product (service) on the environment during its whole life cycle,
- analysis of probability of appearing mutually connected environmental impacts in such a way as protective means used not lead to the appearance of next problems,
- agreement of preferences in improving products, and
- possibility of comparing heterogeneous solutions of the same issue or different methods of realizing the same process.

Fig. 1. presents the procedure of conducting the Life Cycle Assessment, whose first stage is to define the aim and scope of the studies. The aim of the research should define clearly the intended use, reasons for whose the studies are carried out and also the receiver of the results. The aim of the research defines the level of

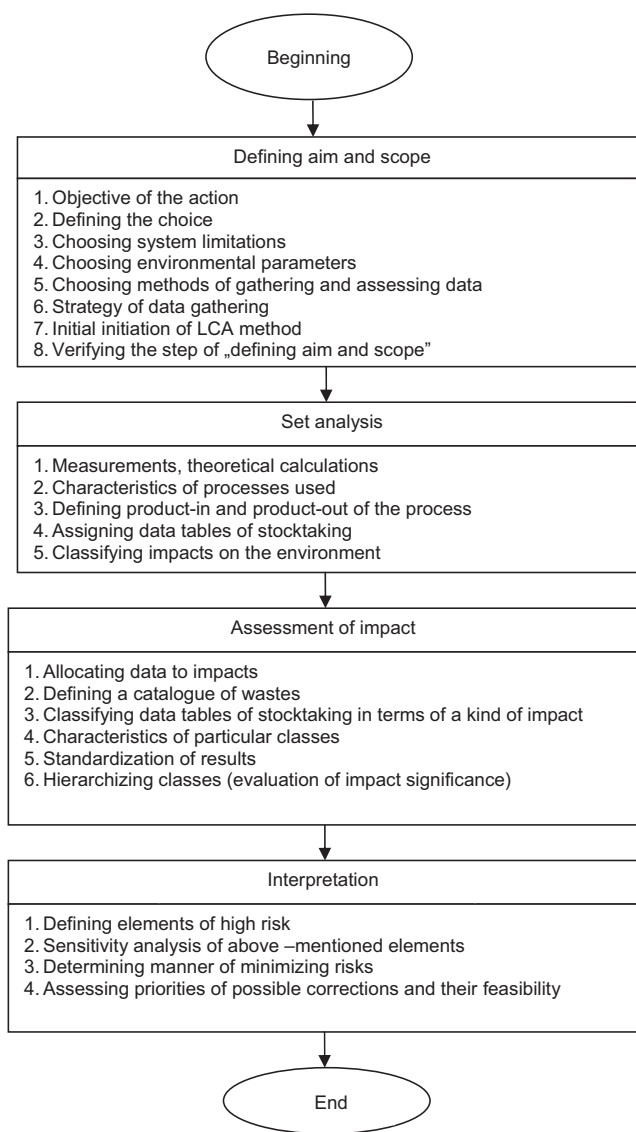


Fig. 1. The procedure of LCA.

Source: [21] Wach 2002, p. 92.

accuracy of LCA and the range of research is described by individual processes, its borders and functional unit. A functional unit is the smallest unit accepted for the research, which becomes the quantitative effect of LCA system. Its main task is to provide a reference point for standardizing data-in and data-out of a particular system, which causes that it should be defined explicitly and be measurable. In the case of the assessment of the impact on the environment of producing energy through burning different energetic resources or generating energy from renewable sources, it can be 1 MWh.

The set analysis in life cycle is based on gathering data and selecting calculating procedures, it defines ins and outs for the examined product in the period of its life cycle. The data is gathered in order to prepare a balance of all energetic and chemical elements absorbed from the environment. ISO norms recommend the following support actions in a suitable system of a product:

- Preparing detailed diagrams of processes' transfers together with existing individual processes and relations between them,
- elaborating a description of all individual processes together with a list of the categories of data related to particular processes,

Table 2

Categories of environmental impact.
Source: [22] Clift 1997, p. 294.

No.	Category	Description
1.	Abiotic impoverishment	Extraction of non-renewable ores of mineral resources
2.	Energy impoverishment	Extraction of non-renewable energy carriers. This category can be included in category 1.
3.	Greenhouse effect	Atmospheric absorption of radiation leading to the increase of global temperature
4.	Ozone hole	Increase of ultraviolet radiation reaching the surface of Earth caused by impoverishment of ozone layer
5.	Water and soil contamination	Exposing biota to toxic substances
6.	Acidification	Increase of water and soil acidity
7.	Contamination of humans	Exposing human health to toxic substances appearing in water, air and soil, mainly with food
8.	Creating photochemical oxidants	Emergence of atmospheric particles causing photochemical smog
9.	Eutrophication	Reduction of oxygen amount in water or soil by emission of substances causing increase of biomass production

- preparing a description of methods for gathering data and methods of calculating,
- elaborating instructions regarding the places of gathering data, and
- elaborating a catalog which includes measuring units.

Interpretation is a phase of Life Cycle Assessment, whose task is to analyze conclusions, check completeness, analyze sensitivity, other analyses, recommendations and report. Moreover, this phase allows for defining elements of great risk, analysis of sensitivity of above mentioned elements, to define the manner of minimization of threats as well as assess priorities of possible corrections and their feasibility. The impact assessment allows for defining trustworthiness of results at a high level and formulated conclusions and elaborated recommendations become a complete and objective report from the research. The assessment conducted according to the mentioned procedure allows for presenting the results of impact in relation to nine impact categories included in Table 2 [20]. The International Organization for Standardization (ISO) has defined the following two objectives of life cycle interpretation:

- To analyze results, reach conclusions, explain limitations and provide recommendations based on the findings of the preceding phases of the LCA and to report the results of the life cycle interpretation in a transparent manner; and
- to provide a readily understandable, complete and consistent presentation of the results of an LCA study, in accordance with the goal and scope of the study.

The results of LCA analysis are expressed in eco-indicator points (Pt), where 1 Pt of eco-indicator is a value representing one thousandth of the annual environmental load per one inhabitant of Europe.

3. Results

As energy in the form of electricity is an important input into many industrial processes, and as there are several alternatives for energy production, many LCAs on electricity production have been carried out at numerous institutes and companies throughout the world. Combined production of electricity and district heating has also been studied. Emissions that are considered are greenhouse gases, sulfur dioxide, nitrogen oxides, particles and radioactive materials [23]. Emissions of greenhouse gases and other atmospheric pollutants arise from other stages of the life cycle than power generation. Such stages are raw material extraction, component manufacture, fuel and material transportation and construction and dismantling of facilities. The emissions from these stages depend on many different factors, for example, the country-specific mix of electric power production. In countries where most

of the electricity is produced from fossil fuels combustion, the emissions are greater than in countries using fewer fossil fuels in power production.

The aim of the chapter is to compare the environmental impact of local (small) power plants in Lubin and Polkowice, which are the example of using local, distributed sources of heat and electricity with large power plants, for which cogeneration is a marginal part, i.e. Opole and Dolna Odra power plants. In order to demonstrate the differences of the environmental impact assessment of the local heat and power plants mentioned earlier in relation to power plants, in which the use of thermal energy (cogeneration) is definitely on a lower level, the material-energetic inputs and outputs for two consecutive years of operation (2010, 2011) were compared.

LCA is a technique to assess the environmental aspects and potential impacts associated with a product, process or service, by the following:

- Compiling an inventory of relevant energy and material inputs and the associated emissions to the environment;
- evaluating the potential environmental impacts associated with identified inputs and
- emissions; and
- interpreting the results to facilitate making a more informal decision.

Inputs may be divided into the following stages:

- Raw materials;
- manufacturing;
- use/reuse/maintenance; and
- recycle/waste management.

Outputs may be listed as the following:

- Products;
- atmospheric emissions;
- waterborne wastes;
- solid wastes;
- Co-products; and
- other releases.

Table 3 demonstrates the material and energy inputs and outputs, due to small statistical differences occurring in the analyzed years, only data for 2010 was presented.

Lubin Heat and Power Plant and Polkowice Heat and Power Plant are the part of “Energy” Ltd company, which is engaged in the production of heat and electricity. The owner of “Energy” Ltd with 100% shares is KGHM Polish Copper S.A. Lubin Heat and Power Plant produced in 2010 1,095,171 GJ of thermal energy and 45,246 MWh of electricity and respectively 1,354,593 GJ and

Table 3

Material and energy inputs and outputs for 2010 in relation to 1 GJ of thermal energy production.

Source: Own study.

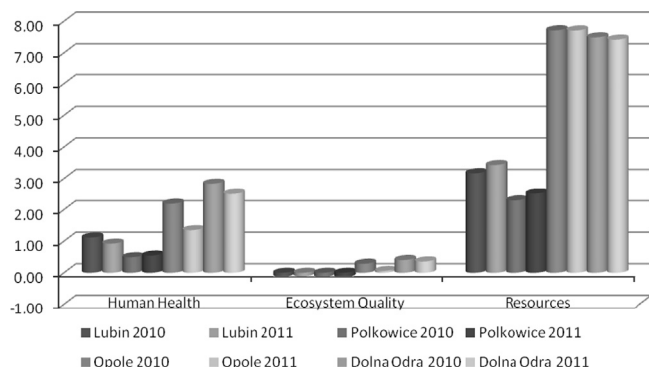
	Dolna Odra power plants	Opole power plants	Polkowice heat and power plant	Lubin heat and power plant
Material and energy inputs				
Coal consumption, ca. 26 MJ/kg [Mg]	3.60	3.32	0.06	0.07
Material and energy outputs				
Production of electricity [MWh]	8.95	7.81	0.04	0.05
Sulfur dioxide [kg]	17.18	4.92	13.01	1.0
Carbon dioxide [kg]	879.85	6835.93	133.20	159.34

Table 4

LCA results of two heat and power plants: Lubin, Polkowice and system power plants: Opole, Dolna Odra—three damage categories in [Pt].

Source: Own elaboration.

Damage category	Lubin 2010	Lubin 2011	Polkowice 2010	Polkowice 2011	Opole 2010	Opole 2011	Dolna Odra 2010	Dolna Odra 2011
Human health	1.12	0.92	0.49	0.55	2.19	1.35	2.84	2.50
Ecosystem quality	−0.12	−0.11	−0.13	−0.14	0.29	0.06	0.41	0.36
Resources	3.17	3.43	2.30	2.51	7.71	7.71	7.49	7.42
Total	4.17	4.24	2.66	2.92	10.19	9.12	10.74	10.28

**Fig. 2.** LCA results of two heat and power plants: Lubin, Polkowice and system power plants: Opole, Dolna Odra—three categories of damage in [Pt].

Source: own study.

52,822 MWh in 2011. Whereas Polkowice Heat and Power Plant produced in 2010 1,271,528 GJ of thermal energy and 45,818 MWh of electricity and respectively 1,141,447 GJ and 41,126 MWh in 2011. Both power plants are powered by coal.² Lubin power plant (141.0 MWt) has the following:

- 4 stoker boilers, including 2 steam boilers type OR-32/80 × 500 and 2 steam boilers type OR-32/50-N (modernized and put into operation in 2012),
- 1 hot water boiler type WLM-25,
- 1 hot water boiler type WLM-25/EM, and
- 2 backpressure turbine units and 1 condensing turbine (27.4 MWe).

Polkowice Power Plant, however, is equipped with the following:

- 2 steam boilers type OR-32/50-N,
- 5 hot water boilers, including: 3 of type WR-25, 1 of type WR-25-014 M, 1 of type WLM -25-N,
- 1 backpressure turbine (10.4 MWe).

Opole Power Plant is a condensing block thermal power plant with a closed-circuit of cooling water. At present, it operates 4 power units started in 1993–1997 with a total installed capacity of 1492 MW. The main fuel is coal. All units are equipped with a wet FGD. The electricity production capacity of Opole Power Plant is about 10 TWh per year and it produces electricity for National Power System and thermal energy for customers located in its vicinity.

Dolna Odra Power Plant is a system power station which was built in the seventies of the twentieth century. Particular units were transferred into operation in 1974–1977. The plant has eight blocks with a total capacity of 1772 MW of electricity. It is a conventional block power plant with an open cooling system. In the 90s Dolna Odra Power Plant implemented a comprehensive program of modernization of major energy facilities. The production of Dolna Odra Power Plant is intended for National Power System and for heat supply for the city of Gryfino. The core business of Dolna Odra Power Plant is the production and distribution of electricity and heat from coal.

The aim of the research is to determine and compare the environmental impact of the electricity production based on coal with the use of LCA analysis. In the time of the research the computer program SimaPro 7.1 was applied. As a functional unit, 1 GJ of produced thermal energy was adopted. The functional unit should be clearly defined and measurable, as it provides a reference platform for the normalization of the input and output data of the reference system.

The scope of the research includes two years of the plants' operation (2010, 2011). The product system concerns material and energy inputs—such as coal, biomass, electricity and others, as well as material and energy outputs—produced electricity and heat, with undesired products, that is pollution.

The analysis of LCA results in relation to three categories of damage (Table 4 and Fig. 2) shows that the greatest impact on the environment in the studied power plants is attributed to the category “raw materials”, which is associated first of all with the consumption of coal for the energy production. In the category “human health” Polkowice Power Plant is characterized by the lowest impact on the environment among the plants concerned. A negative value for the category “eco-system quality” in the case of Lubin and Polkowice power plants is the result of using co-generation, which generates an environmental benefit. The lowest

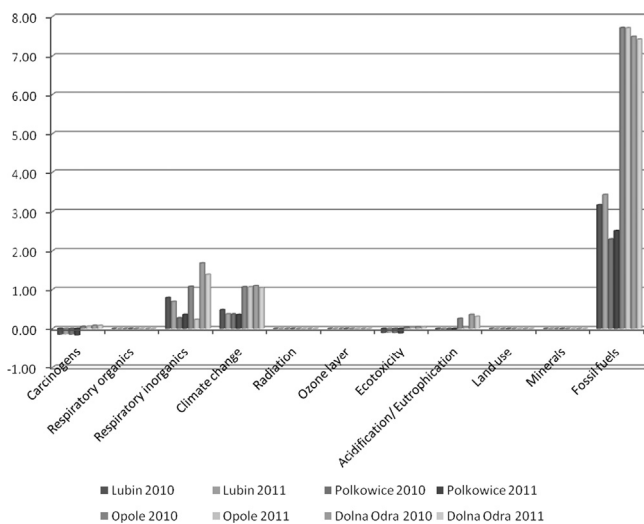
² Data obtained from “Energy” Ltd.

Table 5

LCA results of two heat and power plants: Lubin, Polkowice and system power plants: Opole, Dolna Odra—eleven impact categories in [Pt].

Source: Own study.

Impact category	Lubin 2010	Lubin 2011	Polkowice 2010	Polkowice 2011	Opole 2010	Opole 2011	Dolna Odra 2010	Dolna Odra 2011
Carcinogens	−0.15	−0.14	−0.15	−0.17	0.06	0.06	0.08	0.08
Respiratory organics	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Respiratory inorganics	0.79	0.69	0.27	0.36	1.07	0.23	1.67	1.38
Climate change	0.48	0.37	0.37	0.36	1.06	1.06	1.09	1.04
Radiation	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ozone layer	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ecotoxicity	−0.11	−0.10	−0.11	−0.12	0.03	0.03	0.05	0.05
Acidification/Eutrophication	−0.01	−0.01	−0.02	−0.02	0.26	0.03	0.36	0.31
Land use	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Minerals	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fossil fuels	3.17	3.43	2.30	2.51	7.71	7.71	7.49	7.42
Total	4.17	4.24	2.66	2.92	10.19	9.12	10.74	10.28

**Fig. 3.** LCA results of two heat and power plants: Lubin, Polkowice and system power plants: Opole, Dolna Odra—eleven impact categories in [Pt].

Source: own study.

values for the category “raw materials” in CHP Polkowice are due to the highest efficiency of electricity and heat production. The average efficiency of electricity and heat production in Polkowice Power Plant was 81.73% in 2010 and 81.85% in 2011. In the case of CHP Lubin, the efficiency of generating electricity and heat was 74.10% in 2010 and 68.91% in 2011. In Opole station the efficiency of electricity production in 2010 and 2011 was at the level of 36%, whereas in Dolna Odra plant it was about 33% in the analyzed years. In line with the decrease of the efficiency of energy production in the power plants in study, there is an increase of the value for the damage category “raw materials”. Other variables have also the impact on the value for the category “raw materials”. They are: the calorific value of coal, the distance of power plant from the place of material extraction (in material and energy flows the influence of transport was included). It is also necessary to pay attention to the differences in the results of the category “human health”.

Analyzing the results for eleven impact categories (Table 5 and Fig. 3) it is necessary to notice that the greatest impact on the environment is in the category “fossil fuels” and significantly influences the final LCA result. “Non-organic compounds” are the impact category, which is characterized by the highest difference in the obtained results. This is mainly due to the quality of burned fuel (coal) as well as the type of burned biomass, the temperature of combustion and the amount of the air supply. The results

of the other impact categories in both heat and power plants were similar.

Energy production by burning coal has a negative impact on the environment, which is caused not only by the depletion of non-renewable resources, but also harmful emissions into the atmosphere that degrade the condition of the environment. Moreover, analyzing the profitability of energy production from hard coal, due to the necessity to pay the fees connected with the emission of CO₂, it will be less and less profitable or the prices of electricity will have to increase in Poland. However, despite the significant environmental impact of energy generation in coal-fired power plants and costs related to the adaptation of energy production technology to the strict regulations promoting ecological ways of producing energy, which are less environmentally damaging, due to own resources of coal in Poland, the reduction of the share of energy produced from coal will be a slow process, spread over many years.

The factor hindering the development of electricity production in Poland with the use of other technology than burning coal is first of all the high cost of investment and operation of power plant using other energy fuels. This problem also refers to energy production from renewable energy sources.

Despite a significant negative impact on the environment presented in the analyzed local Power Plants (Lubin and Polkowice) it is necessary to highlight that this impact is much lower than in the case of system Power Plants (Opole and Dolna Odra), the difference in the total impact on the environment between the most extreme values (local CHP Polkowice—system power plant Dolna Odra) is over 400% (see Table 5 and Fig. 3). This is mainly due to more effective use of “waste” heat in local heat and power plants. CHP Polkowice supplies the city of Polkowice with thermal energy, the city which is inhabited by 23,000 people.³ Lubin, where thermal energy is provided by Lubin Heat and Power Plant, has a population of about 75,000.³

In large system power plants “waste” heat is used in small quantities for domestic hot water and central heating, which has a significant impact on the energy efficiency in the end. Opole and Dolna Odra coal-fired power stations, as mentioned earlier, obtain the efficiency oscillating around 40%. Smaller, local heat and power plants have possibilities to optimize the produced amount of electricity and heat in co-generation for local inhabitants.

The production of Dolna Odra Power Plant is intended for National Power System and for the heat of the town of Gryfino, with the population of only 21,000.³ The core business for Dolna Odra Power Plant is the production and distribution of electricity and heat from coal.

³ Data from 2011.

The basic business for Opole Power Plant is the production and distribution of electricity and heat for about 120,000 people.³ Opole Power Plant is a condensing block thermal power plant with a closed circuit of cooling water.

4. Discussion

As a Member State of the European Union, Poland actively participates in devising the Community energy policy, it also implements its main objectives under the specific domestic conditions taking into account the protection of interests of customers, the energy resources and technological conditions of energy generation and transmission.

In line with the above, the primary directions of Polish energy policy are as follows:

- To improve energy efficiency;
- to enhance security of fuel and energy supplies;
- to diversify the electricity generation structure by introducing nuclear energy;
- to develop the use of renewable energy sources, including biofuels;
- to develop competitive fuel and energy markets; and
- To reduce the environmental impact of the power industry.

The adopted directions of energy policy in Poland are largely correlated. Improvement of energy efficiency reduces the increase in demand for fuels and energy, and thus it is conducive to enhancing energy security by reducing dependence on import; it also reduces the environmental impact of the power sector by reducing emissions. The development of renewable energy sources, including the use of biofuels and clean coal technologies, and introduction of nuclear energy bring about similar effects.

Implementing measures in accordance with the above directions, the energy policy will strive to enhance the country's energy security observing the principle of sustainable development.

Improving energy efficiency is one of the priorities of the EU energy policy, whose goal is a 20% reduction in energy consumption by 2020 as compared to the "business as usual" scenario. Poland has made significant progress in this respect. Although GDP energy intensity declined by 30% within the last 10 years, efficiency of the Polish economy calculated as GDP (at euro exchange rate) per energy unit remains twice as low as the European average. Economic development, resulting from the use of new technologies, reveals a considerable increase in electricity consumption accompanied by a relative decrease in the use of other energy forms [24].

Energy efficiency is given priority in the energy policy; and progress in this respect will be of key importance to implementing all of its objectives. Therefore, all possible steps will be taken to enhance energy efficiency.

The analysis proves that the smaller the city (Polkowice) optimally matched to the size of the production of thermal energy, the smaller the environmental impact, it results from, as mentioned earlier, the increase of the efficiency of using co-generation. It is necessary to notice that in any of the analyzed localities (and in the whole Poland) there is no prescriptive system of connecting buildings to the heating network, therefore not all residential buildings use co-generation. Most of them are residential houses, public buildings, business enterprises, schools, etc. Unfortunately, among the mentioned buildings there are also those ones, which resign from thermal energy supplied from a centralized network. This is mainly due to economic conditions, the owners of apartments in multi-family housing, forming communities, look for savings, especially within the supply of energy utilities. The

remedy for this state of affairs would be to use a system of financial instruments, which would affect ecologically and economically sustainable choices made by inhabitants.

Uncertainties about the results create a challenge to using those results in policymaking. Since results are site-specific, it is not easy to draw generic conclusions from LCA studies. First, there is a generalized lack of methodological consistency across different sources.

Although the International Organization for Standardization (ISO) has issued a series of standards (ISO 14040 and 14044) that lay down the basic concepts and general procedures for performing an LCA, these standards are still very general and require ad hoc interpretation when they are to be applied to the assessment of energy systems. This lack of clear and specific guidelines is reflected in many available LCA reports, which also lack harmonization and transparency regarding their methodological assumptions (choice of system boundaries, allocation procedures, type of emissions to trace, etc.) [23].

5. Conclusions and policy implications

Poland energy policy assumes using coal as the main fuel for the power industry in order to ensure an adequate level of energy security of the country.

Specific objectives in the field are as follows [2]:

- Ensuring energy security of the country by meeting domestic demand for coal, ensuring stable supplies to customers and the required qualitative parameters;
- use of coal in the energy industry by application of efficient and low-emission technologies, including coal gasification and processing it into liquid or gas fuels;
- using modern technologies in the coal mining sector to enhance competitiveness, work safety, environmental protection, and to establish the basis for technological and scientific development; and
- maximum use of methane released when extracting coal in mines.

To accomplish the above objectives, the following measures will be taken [2]:

- Introducing regulations which take into account the objectives proposed under the energy policy, particularly instruments motivating to carry out preparatory work and to retain appropriate level of mining capacity;
- developing modernized pre-treatment technologies for coal to be used for energy production;
- abolishing legal barriers to making new deposits of hard coal and lignite available;
- identifying strategic national resources of hard coal and lignite and protecting them through inclusion in spatial development plans;
- securing access to coal resources via undertakings making available new, documented, strategic deposits and their industrial use—through public purpose investments of supra-local significance;
- intensifying geological research to extend the coal resource base, making use of state of the art prospecting and surveying techniques;
- completing organizational and structural changes. In economically justified cases, allowing the possibility to establish capital groups on the basis of coal and energy companies, observing the principles of social dialog;
- supporting the industrial use of methane released when extracting hard coal in mines;

- introducing technology solutions which allow recovery of methane from ventilation air pumped out of hard coal mines;
- obtaining funds for development of the mining industry through privatization, after consultations with social partners. Legitimacy of privatization, the volume of shares, and the IPO date will be analyzed in terms of energy policy objectives;
- supporting research and development of technologies permitting to use coal for liquid and gas fuels production, mitigating the negative environmental impact of processes of obtaining energy from coal as well as coal fuel cells technologies; and
- retaining the competence of the minister in charge of the Treasury in respect of mining companies by the Minister of Economy.
- Life cycle evaluation of emissions from energy production has been the principal target of studies because of international conventions for emission control and the direct and indirect impacts on health and environment.

Energy production in heat and power plants based on coal, undoubtedly has a negative impact on the environment. It is necessary to look for solutions, which will help to reduce a negative environmental impact related to energy generation. An alternative for conventional energy sources can be the use of renewable sources of energy, however, the use of most of them in Polish conditions becomes economically unjustified. The energy system in Poland was mainly based on the location of power plants in close proximity to the sources of fossil fuel [25,26]. The core of currently used solutions is to increase the efficiency of using the generated energy. It can be obtained by the improvement of thermal insulation of buildings, improvement of the insulation of heating infrastructure, modernization of heat sources, but also, what was stated in *Polish energetic policy*, by the change of the energy production structure towards low carbon technologies as well as associated and distributed sources using co-generation.

The Polish systems of instruments for environment law lacks these ones that would significantly affect making decisions by the owners of apartments in the context of sustainable development [27]. Creating a system of incentives (e.g. economic benefits for citizens using the heating network of distributed heat and power plants) would substantially contribute to the reduction of the environmental impact of low emissions in Polish cities.

Assigned environmental loads and conditions resulting from the availability of energy resources in Poland (the availability of local resources of coal and lignite) determine the search for technologies based on coal, which will affect the environment in a smaller degree. The amended *Environmental Protection Act* sets requirements, both to economic operators and individuals, within the improvement of air quality in accordance with the requirements of CAFE Directive.⁴ The law recommends the following:

- The inclusion of building heating systems to centralized heating systems,
- in the case of no possibility to connect buildings to the heating network—determining the method of supplying with heat with preference given to the following heating factors: natural gas, liquefied petroleum gas, light fuel oil, electricity, renewable energy,
- the use of local coal-fired boilers, until they are replaced by a centralized system or modernization using modern low-emission boilers, only fuels with low ash content,

- the development of central systems for thermal energy supply, and
- the change of fuel for another, with smaller ash content or the use of electricity and individual sources of renewable energy,
- the reduction of thermal heat demand due to the limitation of heat losses through thermal modernization of buildings,
- the reduction of emissions from low diffused technological sources, and
- the change of technology and raw materials used in crafts, services and small craft affecting the reduction of the emission of dust.

However, most of the suggestions articulated above is only a record of laws, which have not been implemented due to, as mentioned earlier, the lack of legal instruments encouraging their use [28].

The ecological assumptions of *Polish energetic policy* [2] turn out to be environmentally correct in the context of the conducted LCA analysis of two local power plants and two system power plants, which was the aim of the paper.

LCA evaluation is an important element of a complex approach, taking into consideration the whole life cycle of a particular product and can be an effective tool supporting decision-making in the energy sector. Due to the benefits described in this article, the method of LCA can be used to identify the strategic direction of the energy sector in Poland.

Moreover, due to LCA results it is possible to select proper solutions minimizing negative impact on the environment of individual companies in the energy sector. It is very important for the social and environmental aspects of their operations. Considering manners of obtaining energy from accessible analyzed resources there are many aspects, as not only economic reasons and environment protection against pollution become essential, but also other numerous important factors, such as e.g. the amount of existing non-renewable energy resources. The use in this regard LCA may be an important determinant of corporate social responsibility energy sector.

Questions pertaining to energy accessibility (related to the direct costs of energy), energy availability (related to the security/reliability of supply) and energy acceptability (environmental impacts and externalities) form a framework for decision-makers that helps measure the relative merits of different options. LCA can be useful in matters related to environmental impacts, but only a subset of these impacts is normally included in an LCA. It can also be argued with reason that some of the externalities cannot be covered by the LCA methodology—or any other analytical method—but must be addressed within the political process. Adding LCA to the decision-making process provides the understanding of impacts on human health and the environment not traditionally considered when selecting a product or process. This valuable information provides a way to account for the full impacts of decisions, especially those occurring outside the site, that are directly influenced by the selection of a product or process. LCA is a tool to provide better information for decision-makers and should be included with other decision criteria such as cost and performance to make a well balanced decision. In some cases, it may not be possible to state that one alternative is better than the others because of uncertainty in the final results. This does not imply that efforts have been wasted. The LCA process will still provide decision-makers with a better understanding of the environmental and health impacts associated with each alternative, where they occur (locally, regionally or globally) and the relative magnitude of each type of impact in comparison to each of the proposed alternatives included in the study. This information more fully reveals the pros and cons of each alternative.

⁴ Directives 2008/50/WE of European Parliament and European Council from 21 May 2008 on the air quality and cleaner air for Europe.

In electricity generation systems, plants with different operational characteristics are included. The system characteristics play an important role in making decisions on new plant investments. In some cases, co-production of power and heat may be feasible.

Summarizing, LCA analysis can be used as a universal tool to assess the impact of products, services as well as plans, policies and strategies of actions on the environment in different sectors of the economy. So far the analysis of LCA has been used at the stage of designing and production or providing a service to determine the size of the impact on the environment. A prerequisite for the use of this method to assess is the occurrence of material and energy flows in the analyzed phenomena. The adoption of the appropriate allocation model and determination of the quality of data necessary for the analysis. LCA analysis can be considered as fully useful also to assess the assumptions of strategic documents including *Polish Energy Policy* as well.

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